

## **EFFECT OF HHO GAS AS FUEL ADDITIVE ON THE EXHAUST EMISSIONS OF INTERNAL COMBUSTION ENGINE**

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### **ARTICLE INFO**

#### **Article History:**

Received: 14 Mar 2019;

Received in revised form:

04 Apr 2019;

Accepted: 04 Apr 2019;

Published online: 10 Apr 2019.

#### **Key words:**

Oxyhydrogen Gas,  
Internal Combustion Engine,  
Environmental Pollution,  
Brown's Gas,  
HHO Gas Generator,  
Fossil Fuel Emissions

### **ABSTRACT**

The use of carbon-base fuels by diesel engines release gases such as CO, NO<sub>x</sub>, SO<sub>2</sub>, and THC<sub>s</sub> which constitute a major source of environmental pollution. These gases when released into the atmosphere result in the formation of acid rain and cause greenhouse effect. In the present study, an experiment was carried out with and without the use of HHO gas. The concentrations of the emitted gases were measured using an E8500 Plus gas analyzer. The results showed that the average concentrations of carbon monoxide (CO), total unburnt hydrocarbons (THC<sub>s</sub>), oxides of nitrogen (NO<sub>x</sub>) and sulphur dioxide (SO<sub>2</sub>) emitted from the combustion chamber of the test engine was decreased by 68.8%, 35.2%, 16.4% and 97.9% respectively when a mixture of HHO gas/petrol/air was used instead of petrol/air mixture in an internal combustion engine. However, the average concentration of oxygen (O<sub>2</sub>) gas increased by 1.7%.

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### **HIGHLIGHTS**

- 1) Production of a proton exchange membrane fuel cell.
- 2) Production of HHO gas using KOH as catalyst.
- 3) Measurement of HHO gas flow rate.
- 4) Modification of the petrol engine using a proton exchange membrane fuel cell.
- 5) Determination of performance of HHO gas on emission characteristics of a petrol engine.

### **INTRODUCTION**

The transport industry accounts for 95% of all energy consumption produced worldwide using conventional liquid fuels (International Energy Outlook, 2017). This establishes that the transportation industry is heavily dependent on liquid fossil fuels as

**Cite this article as:** Essuman, S. P. K., Nyamful, A., Agbodemegbe, V. Y., & Debrah, S. K., "Effect of HHO Gas as Fuel Additive on the Exhaust Emissions of Internal Combustion Engine". *International Journal of Advanced Scientific Research & Development (IJASRD)*, 06 (03/I), 2019, pp. 01 – 12. <https://doi.org/10.26836/ijasrd/2019/v6/i3/60301>.

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compared to their use for electricity generation. The over dependency of existing Internal Combustion Engines (ICEs) on fossil oils have resulted in the emission of high concentrations of greenhouse gases that include  $\text{NO}_x$ , CO,  $\text{O}_3$ ,  $\text{SO}_x$ , and  $\text{CO}_2$  (Naresh C. *et al.*, 2014). The continual increase in the concentration of carbon dioxide in the atmosphere is observed to be a main contributing factor to the increase in temperature of the earth between  $2^\circ\text{C}$  to  $4^\circ\text{C}$  leading to global warming (EL-Kassaby MM. *et al.*, 2016).

In the quest to transit towards lowering fossil fuel consumption as well as to reduce its associated pollutants emitted from these Internal Combustion Engines (ICEs), researchers are currently seeking for alternative fuel sources such biodiesel, bioethanol, and biogas which require no modification to existing engines. However, these fuels are commercially expensive (Özcanli M. *et al.*, 2016). Another method gaining global attention is the blending of HHO gas with petrol as a supplementing fuel to enhance the performance and to reduce the concentrations of pollutants emitted from the combustion chamber of these ICEs (Raviteja S. *et al.*, 2014). Literature survey undertaken (2015-2017) show limited research into the reduction or otherwise in the concentrations of  $\text{SO}_2$ ,  $\text{NO}_x$ , CO, and THC's emitted from ICEs using HHO gas blend with petrol. However, the concentration of oxygen and the temperature within the combustion chamber of these engines that affect the production of these gases have not been studied within the period reviewed.

Sachin Jadhav and S.B. Sanap, 2015 studied the effect of HHO gas blending with gasoline on the performance and emission characteristics of a four-stroke single cylinder spark ignition engine. The HHO gas was produced via electrolysis of water and was injected directly into the intake manifold of a 133 cc engine. The test was done in two parts; using gasoline/air and gasoline/HHO gas/air mixtures. The results showed an improvement in engine performance when the gasoline/HHO gas/air mixture was used. In addition, the concentrations of HC and CO was observed to decrease by 58.3% and 71.4% respectively whilst the concentration of  $\text{NO}_x$  increased by 18.8%. The optimization and effect of hydroxy gas on a CI engine performance and emission using biodiesel blend with HHO gas was investigated by M.I. Arbab *et al.*, 2016 and reported that the blend of biodiesel/HHO gas mixture in the CI engine reduced the concentrations of CO and HC emissions by 20% and 10% respectively. Mustafa Ozcanli *et al.*, 2016 confirmed similar results obtained by M.I. Arbab *et al.*, 2016 using HHO (Hydroxy) gas and hydrogen-enriched castor oil biodiesel in a compression ignition engine. Likewise, Husenyin Turan Arat *et al.*, 2016 showed that using hydroxy CNG fuel mixtures in a non-modified diesel engine was able to increase the brake torque, brake power and brake thermal efficiency tremendous. Furtherance to this, P. V. Manu *et al.*, 2016 further studied an on-board dry cell electrolyzer in a CI engine that works on a dual fuel mode. The maximum BTE was reported to increase by 34.99 % at a load of 14.7 kg when an HHO gas flow rate of 2 LPM was used. This result was also affirmed by Harshall Vashi *et al.*, 2016; Patel Chetan N. and Maulik A. Modi, 2016. In a different experiment, the effect of using HHO gas as a fuel additive in a 92255 cc Isuzu trooper engine was done by Sanchez *et al.*, 2016. The test was carried out by varying the engine speed from 754 rpm, 1500 rpm, 2000rpm, and 2500 rpm at varied HHO gas flux of 6,631, 15,461, and 22,389 mL/s. Reduction in the concentrations of CO,  $\text{CO}_2$ , and HC was stated to be 12.18%, 1%, and 32.67% respectively. Also, D. J. Jyothsna Devi *et al.*, 2016 studied the effect of HHO gas/petrol fuel on engine efficiency. Their results disclosed an increase in engine torque and specific fuel consumption by 19.1%, and 14% with a decrease in the

concentration of HC and CO by 5% and 13.5% respectively. This results was also confirmed by Rasik S. Kuware and Dr. Ajay V. Kolhe, 2016 in a similar work. Ahmed H. Sackhrieh *et al.*, 2017 optimized a compression ignition combustion engine using HHO gas as supplementary fuel. They varied the field voltage and speed; maintained the electric dynamometer while the engine throttle was varied. Their results revealed that engine power, torque, brake specific fuel combustion, and efficiency were increased by 14.2%, 4.8%, 10.6% and 8.8% respectively. Similar results were also reported by Pranav Powar *et al.*, 2017. Subsequently, the reduction of emission pollutants in a 99.27 cc single cylinder Bajaj CT 100 gasoline engine using HHO (oxyhydrogen) gas in the intake manifold of the engine was studied by Arvind *et al.*, 2017. Their experimental outcome showed a decrease in the concentrations of CO, HC, and CO<sub>2</sub> by 42%, 16%, and 28% respectively. Furthermore, Ghulam Abbas Gohar and Hassan Raza, 2017 did a comparative analysis of performance characteristics of a compression internal engine TQ200 with and without HHO gas using KOH as catalyst in a leak-proof reactor. Results obtained confirmed an increase in engine brake power, thermal efficiency and mechanical efficiency by 22%, 47%, and 24% respectively while the engine brake specific fuel consumption and the specific fuel consumption were decreased by 35% and 27% respectively.

The present study, therefore, seeks to investigate the effect of oxy-hydrogen gas on the concentration of oxygen and the temperature within the combustion chamber of a 125 cc haojue petrol engine using petrol/HHO gas/air mixture. Other parameters such as the concentrations of SO<sub>2</sub>, NO<sub>x</sub>, CO, and THCs presented in other works were also investigated in this study.

## METHODOLOGY

This session present the material, equipment and methods employed for the experiment conducted.

### 2.1 Equipment

The specifications of the equipment used in the execution of the present study are briefly provided in this section.

#### (a) Haojue Engine

In the present work, Haojue engine was used to burn the petrol/air mixture. The technical specifications of the test engine is as presented in Table 1.

**Table – 1:** *Technical Specification of the Test Engine*

|                 |  |
|-----------------|--|
| Name            | Haojue                                       |
| Type            | 4-Stroke, Single Cylinder, Air-Cooled        |
| Displacement    | 125  |
| Maximum Power   | 5.0 KW @ 7,500 rpm (Maximum Power Converter) |
| Maximum Torque  | 8.0 Nm@4,500 rpm (Maximum Power Converter)   |
| Bore x Stroke   | 52.4 x 49.5                                  |
| Cooling         | Air cooled                                   |
| Starting Method | Electric & Kick Start                        |

|                    |                       |
|--------------------|-----------------------|
| Ignition Type      | DC-CDI                |
| Oil Grade          | 20W50                 |
| Gears              | 4                     |
| Clutch             | Wet, Multi-Plate Type |
| Fuel Tank Capacity | 4.2 Liters            |

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### (b) HHO Gas Electrolyzer

In the present work, the HHO gas electrolyzer was used to produce HHO gas using selected electrolyte solutions and electricity. The electrolyzer is made up of 130 pieces of stainless steel electrodes (SS 316-L) enclosed in a transparent plexiglass. The electrolyzer is equipped with a reservoir tank and a bubbler and is regulated by a uni-directional acetylene gas arrester. Table 2 shows the detailed specification of the HHO gas electrolyzer.

**Table – 2:** *Specification of HHO Gas Electrolyzer Used*

|                   |   |
|-------------------|---|
| Length            | 12 cm                                       |
| Width, Height     | 12 cm, 10 cm                                |
| Number of plates  | 130 316 Stainless steel                     |
| Number of gaskets | 125 Ethylene Propylene Diene Monomer (EPDM) |

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### (c) Rectifier

The rectifier is a device used to convert DC to AC. The rectifier is built to have an adjustable mode to select various voltages for the experiment. The technical specification of the rectifier used is described in Table 3.

**Table – 3:** *Specification of Rectifier*

|                            |              |
|----------------------------|--------------|
| Length                     | 20cm         |
| Width, Height              | 10 cm, 14 cm |
| Rated voltage              | 0 V-16 V     |
| Rated current              | 0 A-13 A     |
| Incorporated safety device | Breaker      |

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### (d) Gas Analyzer

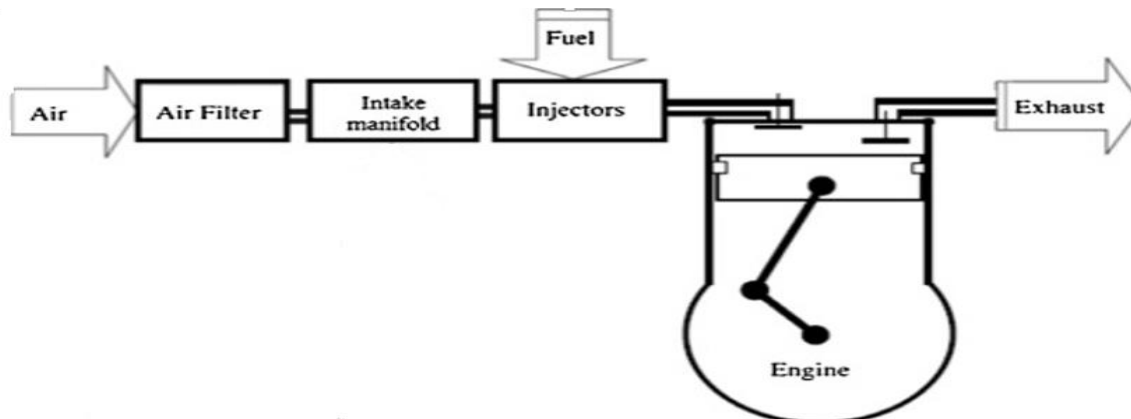
The E8500 Plus gas analyzer was used in the present work for measuring the concentrations of gases emitted from the combustion chamber of a mechanized equipment

## 2.2. Procedure for Emission Test

The fuel tank of the 125 cubic centimeters, 4-stroke, single cylinder and the air-cooled haojue engine was filled with petrol and the engine was switched on allowing the air intake manifold of the engine to draw only air so that the fuel being burnt in the engine was a mixture of petrol and air only. The engine was allowed to equilibrate for a minimum period of 10 minutes. The E8500 Plus gas analyzer was also switched on and allowed to equilibrate for a period of 10 minutes.

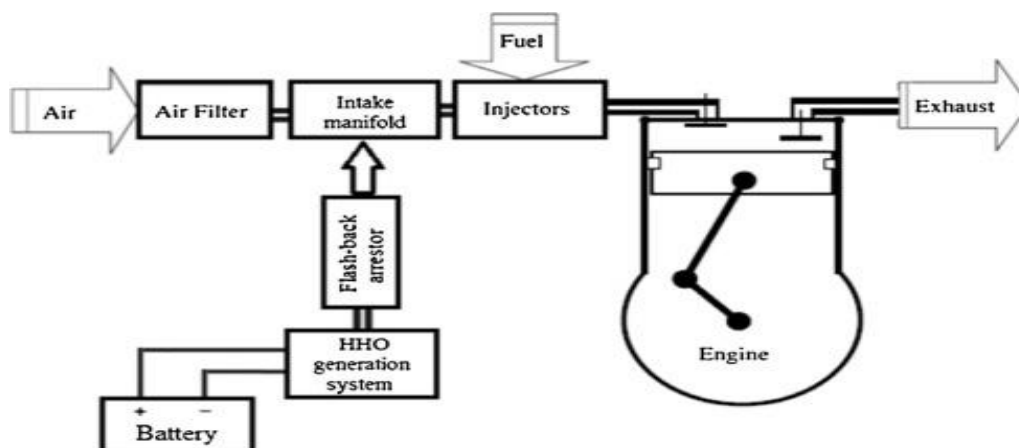
After allowing the gas analyzer to equilibrate, the probe of the gas analyzer was placed just at the end of the exhaust pipe and the concentrations of the emitting gases from the combustion chamber of the engine was measured for a period of 10 minutes.

**Figure – 1:** *Flow Diagram of the Experiment using Petrol and Air Mixture as Fuel*



The procedure was repeated this time, connecting the tube through which the HHO gas runs in the oxyhydrogen electrolyzer to the air intake manifold of the engine via a flow rate meter delivering HHO gas at a rate of 1.2 LPM; so that the fuel being burnt in the combustion chamber of the engine was a mixture of petrol, air and HHO gas only; and the concentrations of the emitting gases was measured as described early on, following the methods used by (Premkartikkumar *et al.*, 2014; Ahmed H. Sakhrieh *et al.*, 2017).

**Figure – 2:** *Flow Diagram of the Experiment Using Petrol, HHO Gas and Air Mixture as Fuel*



## RESULTS AND DISCUSSIONS

Results of the investigations conducted in the present work are presented and discussed in this session.

### 3.1 Concentration of Internal Combustion Emission Components

Table 4 compares the average concentrations of the respective emission components resulting from the internal combustion of Petrol-Air Mixture and Petrol-Air-HHO gas Mixture in the test engine.

**Table – 4:** Average Concentration of Engine Emission Components for Combustion with and without HHO Gas

| Emission Component | Emission Component Concentration for Petrol + Air Mixture | Emission Component Concentration for Petrol + Air + HHO Gas Mixture |
|--------------------|---|---|
| SO <sub>2</sub>    | 4,073.40 mg/m <sup>3</sup>                                | 86.20 mg/m <sup>3</sup>   |
| NO <sub>x</sub>    | 59.80 mg/m <sup>3</sup>                                   | 50.00 mg/m <sup>3</sup>   |
| CO                 | 16,059.40 mg/m <sup>3</sup>                               | 5,017.90 mg/m <sup>3</sup>  |
| O <sub>2</sub>     | 15.96 %   | 17.64 %   |
| THCs               | 3,075.60 ppm  | 1,991.90 ppm  |

Results presented in the table 4 shows that, with the exception of O<sub>2</sub>, there is a general high level of emissions from the test engine in the absence of HHO gas. The concentration-time profile for each of the emission component over a period of ten (10) minutes of operation of the test engine are discussed subsequently.

### 3.2 Profile of SO<sub>2</sub> Emissions for the Cases with and without HHO

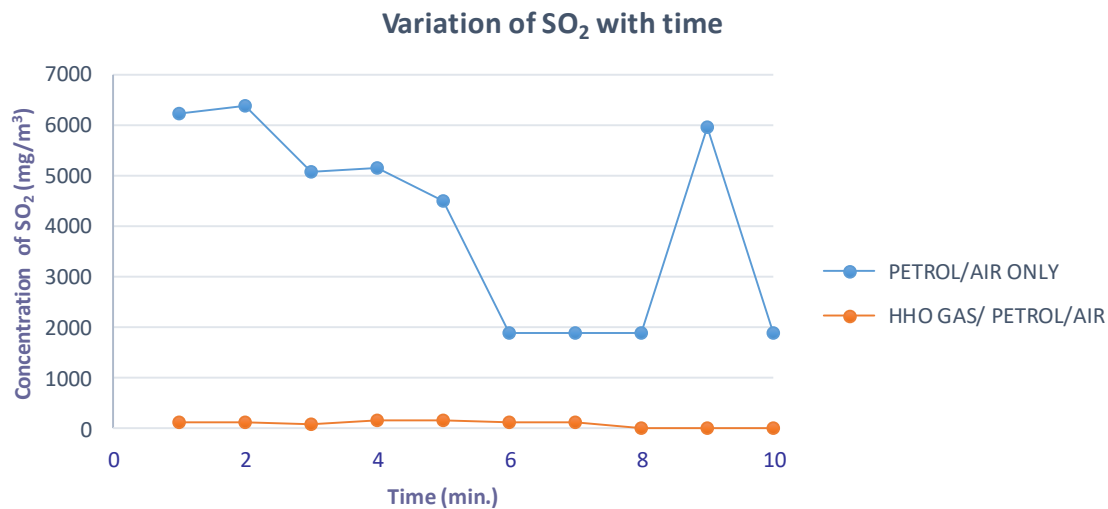
**Figure – 3:** Concentration-Time Profile of Sulphur Dioxide (SO<sub>2</sub>) Emissions from Test Engine

Table 4 shows that the average concentration of SO<sub>2</sub> gas of the emissions resulting from the combustion of petrol/air mixture in the combustion chamber of the test engine was 4,073.40 mg/m<sup>3</sup>. With the introduction of the HHO gas into the petrol/air mixture in the combustion chamber, the average concentration of SO<sub>2</sub> gas decreased drastically from 4,073.40 mg/m<sup>3</sup> to 86.20 mg/m<sup>3</sup> representing 97.9% decrease in the concentration of SO<sub>2</sub> gas. The decrease in the concentration of SO<sub>2</sub> gas may be attributed to the fact that when SO<sub>2</sub> gas reacts with oxygen in the HHO gas, the SO<sub>2</sub> gas is converted to SO<sub>3</sub> gas (Lawrence P. Belo et al., 2014). R.W. Fair and B.A. Thrush, 1969 also reported that when hydrogen in the HHO gas reacts with SO<sub>2</sub> gas, there is an efficient heterogeneous reduction of SO<sub>2</sub> gas to SO<sub>3</sub> gas. These effects may explain the drastic decrease in the concentration of SO<sub>2</sub> gas to almost a constant average value of 86.20 mg/m<sup>3</sup> emitting from the combustion chamber within the measuring period as shown in Figure 3. Additional Oxygen gas provided by the

HHO gas other than that supplied from the air/petrol mixture further enhanced the conversion of  $\text{SO}_2$  gas to  $\text{SO}_3$ . The sharp trend observed for the emission of  $\text{SO}_2$  for the combustion of the petrol/air mixture may be attributed to the unstable nature of the engine speed regulator used for the experiment. However, the decreased and almost linear trend observed for the petrol/air/HHO gas mixture could be due to the high diffusibility and flammability range of hydrogen contained in the HHO gas/petrol/air mixture in the combustion chamber of the engine. This caused more HHO gas to burn compared to the sulphur contained in the petrol/air mixture.

Health exposure to high concentration of sulfur dioxide in air has been associated with reduced lung function, increased incidence of respiratory symptoms and diseases, irritation of the eyes, nose, and throat, and premature mortality (World Bank Group, 1998). Studies have also shown that plants exposed to high ambient concentrations of sulfur dioxide may lose their foliage, become less productive, or die prematurely (World Bank Group, 1998). Acid depositions in freshwater lake and stream ecosystems also lowers the pH of rivers, streams and lakes. Since fish species cannot survive large shifts in pH, most affected lakes can become completely devoid of fish life. Acidification also decreases species variety and abundance of other animal and plant life (World Bank Group, 1998). Sulfate aerosols, converted from sulfur dioxide in the atmosphere has been studied to further reduce visibility by light scattering (World Bank Group, 1998). In connection with materials defect, sulfurous acid formed from the reaction of sulfur dioxide with moisture, accelerates the corrosion of iron, steel, and zinc.

### 3.3 $\text{NO}_x$ Emissions

**Figure – 4:** Concentration-Time Profile of Oxides of Nitrogen ( $\text{NO}_x$ ) Emission from Test Engine

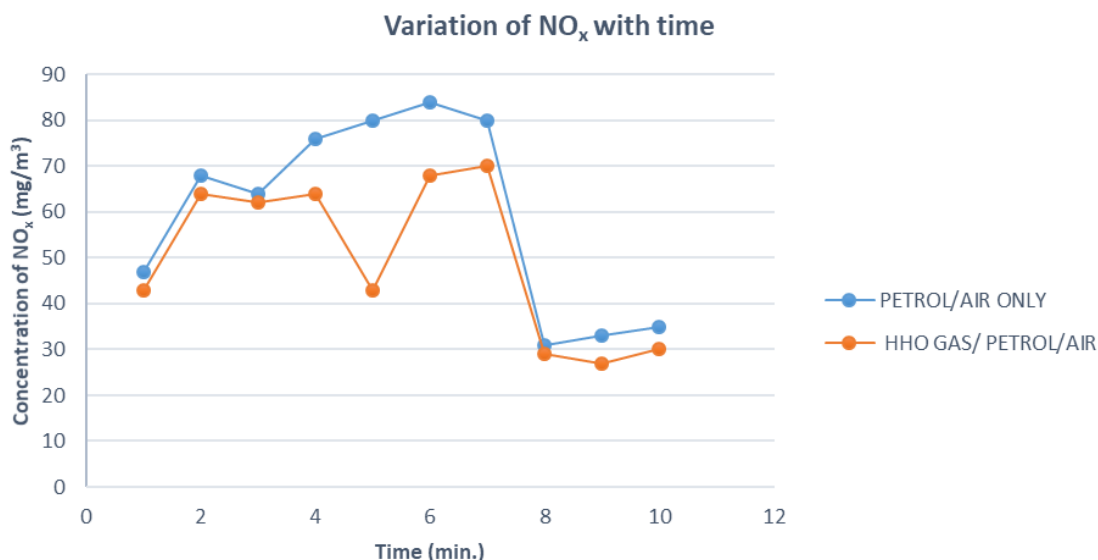
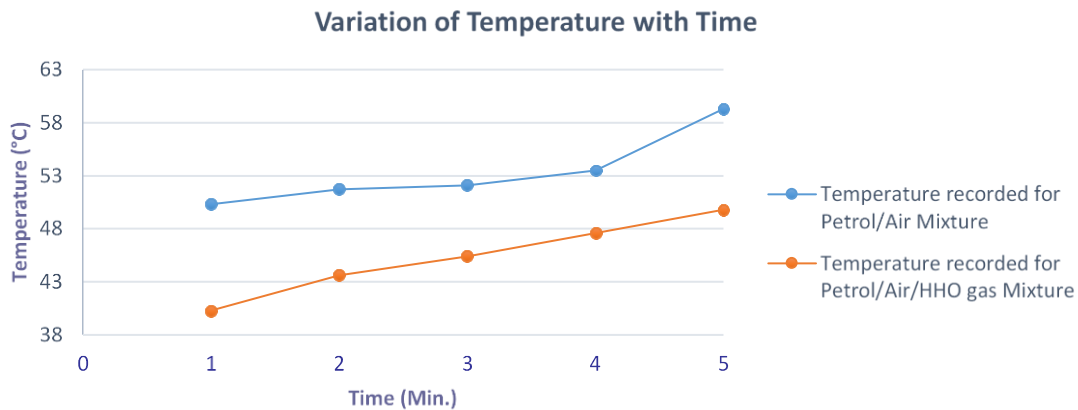


Figure 4 shows that the concentration of  $\text{NO}_x$  gas produced from the petrol/air mixture increased from  $47.0 \text{ mg/m}^3$  to  $84.0 \text{ mg/m}^3$  within the first six (6) minutes of the experiment and then dropped to  $35.0 \text{ mg/m}^3$  at the 10<sup>th</sup> minute giving average  $\text{NO}_x$  gas concentration of  $59.80 \text{ mg/m}^3$  (Table 4). Similar work carried out by Sa'ed A. Musmar and Ammar A. Al-Rousan, 2011 reported that the concentration of  $\text{NO}_x$  gas increased with temperature of the system with respect to time; this may account for the observed increase

in the concentration of NO<sub>x</sub> gas within the first 6 minutes. With the introduction of the HHO gas into the petrol/air mixture, the average NO<sub>x</sub> gas concentration decreased to 50.0 mg/m<sup>3</sup> (Table 4) representing 16.4% reduction. The decrease in the average concentration of NO<sub>x</sub> gas could be attributed to the presence of the HHO gas that reduced the temperature of the system and hence caused unfavorable condition for the formation of NO<sub>x</sub> as observed by Sa'ed A. Musmar and Ammar A. Al-Rousan, 2011 (Figure 5).

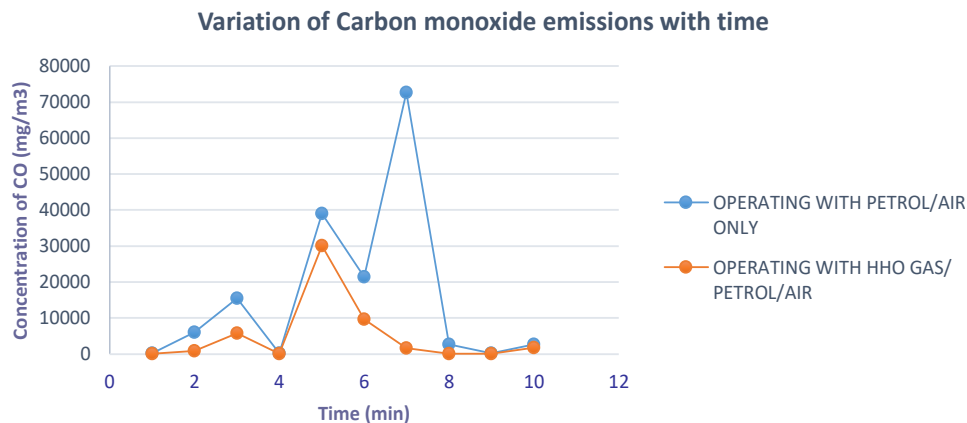
**Figure – 5:** *Temperature-Time Profile for Petrol/Air and Petrol/Air/HHO Gas*



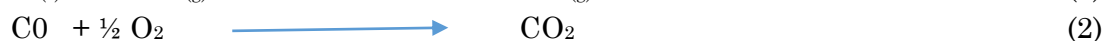
Environmental effect of NO<sub>x</sub> include among others regional air pollution which serves as reactant for production of photochemical smog and also contributes to acid rain which affects plants and animal lives.

### 3.4 CO Emissions

**Figure – 6:** *Concentration-Time Profile of Carbon Monoxide (CO) Emissions from Test Engine*



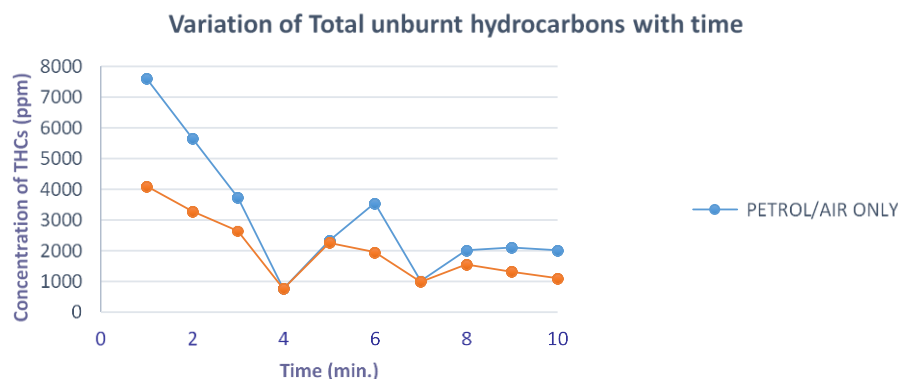
The percentage reduction in the average concentration of CO was found to be 68.8% (Table 4). The decrease in the average concentration of CO in the second experiment could be attributed to the explanation that, the introduction of the HHO gas in the petrol/air mixture caused the level of oxygen in the mixture in the combustion chamber to increase leading to an enhancement in the conversion of CO to CO<sub>2</sub> thereby reducing the CO concentration as observed (Bari S. and Mohammad E.M., 2010). Equations 1 and 2 show the chemical reaction for the conversion of CO to CO<sub>2</sub>.



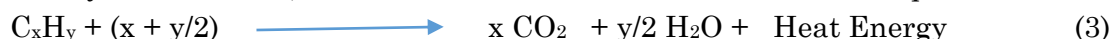
Health effects of CO include the binding of CO to human haemoglobin to form carboxyhaemoglobin which refute the human body of sufficient oxygen, causes headaches, nausea and lethargy.

### 3.5 THC Emissions

**Figure – 7:** Concentration-Time Profile of Total Unburnt Hydrocarbons (THCs) Emissions from Test Engine



The variation of the concentrations of Total unburnt Hydrocarbons (THCs) emissions with time is depicted in Figure 7. The average reduction in the concentrations of THCs was found to be 35.2% (Table 4). This reduction in the average concentration of THCs could be attributed to the increase in the concentration of oxygen gas in the combustion chamber due to the presence of the HHO gas causing reasonable decrease in the average concentration of THCs by converting THCs to CO, CO<sub>2</sub>, H<sub>2</sub>O, and heat energy in line with experiment carried out by Ali Can et al., 2010. This conversion reaction is shown in equation 3.



### 3.6 Oxygen (O<sub>2</sub>) Emissions

**Figure – 8:** Concentration-Time Profile of Oxygen Gas (O<sub>2</sub>) Emissions from Test Engine

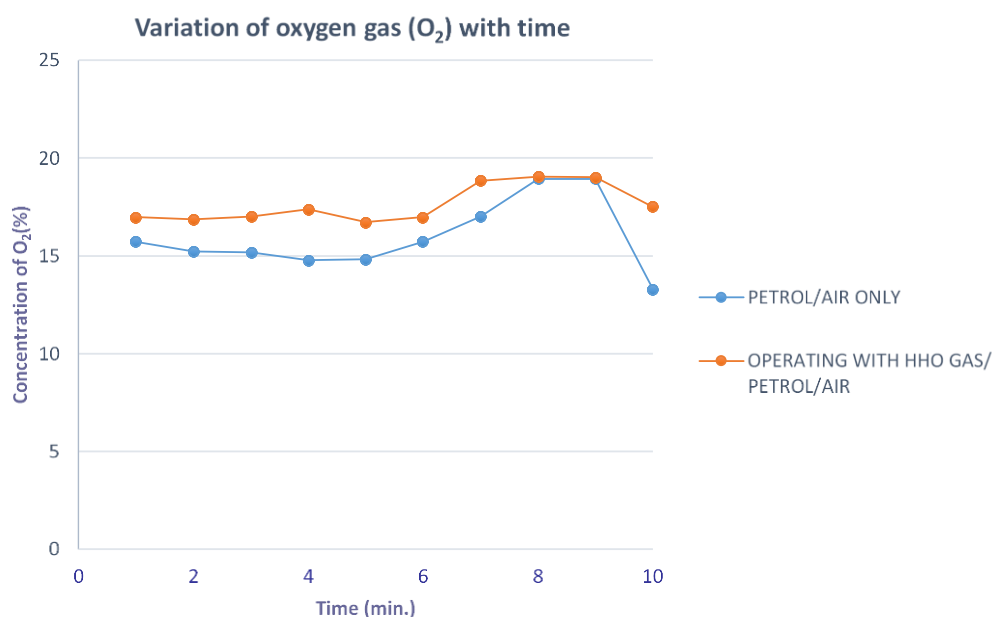


Figure 8 shows that the concentration of oxygen in the HHO/petrol/air mixture in the combustion chamber at any time was higher than the concentration of oxygen in the

petrol/air mixture in the combustion chamber. Overall, the average concentration of oxygen gas increased by 1.7% (Table 4). The increase in the average concentration of oxygen gas emitted could be assigned to the presence of oxygen in the HHO gas introduced into the combustion chamber.

## CONCLUSION

The measurement of gaseous pollutants (CO, NO<sub>x</sub>, THC<sub>s</sub>, and SO<sub>2</sub>) emitted from the exhaust of a 125 cc Haojue engine using HHO gas as a fuel additive to petrol/air mixture was carried out. The average concentrations of Sulphur dioxide (SO<sub>2</sub>), Oxides nitrogen (NO<sub>x</sub>), Carbon monoxide (CO) and Total unburnt hydrocarbons (THC<sub>s</sub>) decreased by 97.9%, 16.4%, 68.8% and 35.2% respectively. However, the average concentration of oxygen gas (O<sub>2</sub>) increased by 1.7%.

It is therefore recommended that, to support efforts at addressing issues of climate change which results from the emissions of gases into the atmosphere, the use of low emitting energy sources should be intensified especially in the automobile industry and other industries that depend so heavily on the burning of fossil fuels.

## ACKNOWLEDGEMENT

I will like to acknowledge Mr. Cephas Kwaku Hammond, Mr. Kwadwo Asamoah Manu, Mr. Agyekum Fred Asante, Mr. Kwame Adum Kwapong, Mr. Cis Crabbe, Miss Catherine Kuamoah and Miss Hephzibah Ewuradjoa Pamford Essuman for their immense support that ensured the successful completion of this study.

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